

# 2 Use of Electromagnetic Energy and Resultant Noises

SUGIURA Akira

Recently, the advent of RF-ID systems and PLC systems have raised a new problem of electromagnetic interference (EMI) between newly developed systems and other various systems including radio stations using the shortwave band. In this connection, EMI limits for a variety of equipment are reviewed and compared in terms of the radiated field strength. Investigations are extended to cover the environmental noises, indicating the necessity for surveying recent noise environments in a large scale.

## **Keywords**

Electromagnetic environment, Electromagnetic disturbance, EMI limit, Man-made noise, PLC

## 1 Introduction

We have recently witnessed explosive growth in the use of 13-MHz band RF-ID systems for automatic ticket gates and security systems. These types of devices are designed to offer a transmission range of up to one meter. Power-line communication (PLC) is another method currently under active consideration in many countries. PLC can enable high-speed communication through an existing utility power grid through the transmission of HF-band current. A variety of new communication systems use this HF band (3 MHz to 30 MHz).

However, concern is growing that unwanted radiation from these systems may interfere with radio services or affect electronic devices and the human body. To address this problem, in 2005 the Ministry of Internal Affairs and Communications (MIC) established the “Study Group on Broadband PLC”. This group studied the requirements entailed by frequency sharing with existing radio services[1]. This paper will discuss issues concerning various electromagnetic environments based on

the results of this study.

## 2 Electromagnetic environments

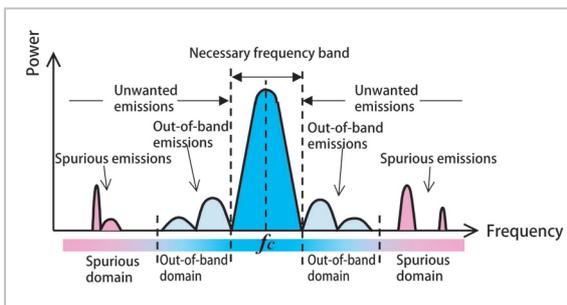
Sources of energy that create an electromagnetic environment include natural phenomena such as thunder, as well as radio equipment, high frequency-based equipment, and other electric and electronic devices. The discussion below deals mainly with HF-band electromagnetic environments and artificial sources of electromagnetic waves.

### 2.1 Radio equipment

HF-band radio waves reflected by the ionosphere are suitable for long-distance communication and have traditionally been used in communications over seas—by passenger and cargo ships, warships, and deep-sea fishing boats. However, since ionospheric conditions vary greatly depending on the time, season, solar activity cycle, and other factors, establishing stable communication channels proved difficult. HF-band communication thus began to be superseded by satellite communications in the 1960’s. However, HF-band radio waves

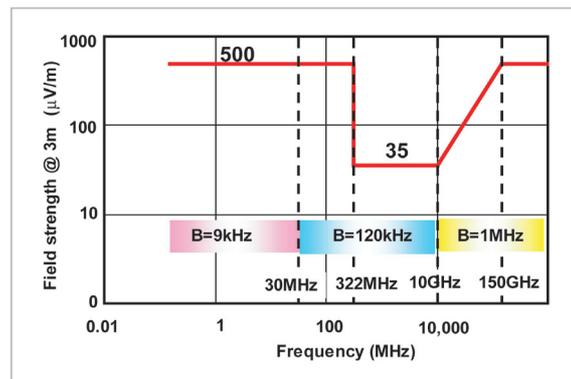
are still used for various purposes—for example, in aeronautical communication (including emergency transmissions), maritime communications (also including emergency transmissions), shortwave broadcasting, ham radio (3.5, 3.8, 7, 10, 14, 18, 21, 24 and 28 MHz), radio astronomy, fixed and mobile communications, 27 MHz citizen band radio, radio microphones, and radio-controlled machines.

These radio services use electromagnetic waves of designated wattages; however, spurious and out-of-band emissions caused by modulation may interfere with other radio services, as shown in Fig. 1.



**Fig. 1** Electromagnetic waves emitted from radio services

To address this problem, the Japanese government restricts spurious emissions from radio services. For example, if the basic frequency of a radio service is 30 MHz or lower, its spurious emissions must be lower than 50 mW and the emissions strength must, in principle, be lowered by 40 dB or more relative to average power at the basic frequency [2]. In many countries, low-power communication equipment may be provided without a license; in these cases the field strength of electromagnetic waves can be limited to levels equivalent to those of unwanted radiation from PCs. In Japan, for example, if the basic frequency is 322 MHz or lower, the field strength is limited to 500  $\mu\text{V}/\text{m}$  at a distance of 3 m; if the basic frequency is somewhere between 322 MHz and 10 GHz, the field strength is limited to 35  $\mu\text{V}/\text{m}$ , as shown in Fig. 2 [3]. At frequencies below the HF band, it is considered appropriate to measure strength at a distance of 10 m instead of 3 m, as the electromagnetic



**Fig. 2** Permissible limits for low-power communication equipment (“B” refers to -6 dB bandwidth of the measuring instrument)

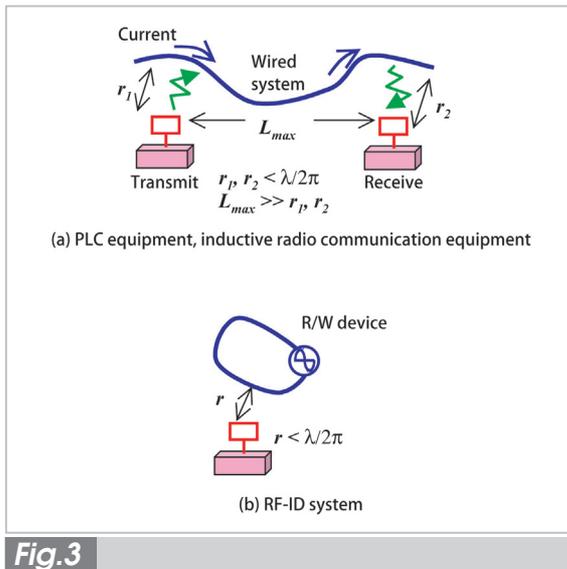
field presents complicated characteristics near the source.

In addition, receivers for radio services generally use heterodyne detection and emit unwanted radiation. Therefore, incidental radiation from these receivers is limited to 4 nW under the Radio Law [4].

## 2.2 High frequency-based equipment

Apart from radio services, various types of devices use electromagnetic energy. Among these, certain equipment is designed to flow signal current of 10 kHz or higher through a wired system in which transmitting/receiving ends are coupled electromagnetically; other types of devices include those that use electromagnetic energy within a shielded space. Both types are classified as “high frequency-based equipment” in Japan [5]. The former type is referred to as “communications equipment”. Figure 3 shows some specific examples of such devices. Devices of the recently high-profile PLC fall under the category indicated in Fig. 3 (a). The latter type mentioned above includes induction cooking appliances and microwave ovens, all of which fall under the category of “medical devices, industrial heating devices, and miscellaneous devices”, although internationally these devices are known as “ISM” (industrial, scientific, and medical) equipment.

The Radio Law in Japan restricts electromagnetic waves leaked from high frequency-



**Fig.3**

based equipment that the Law views as sources of interference with radio services. For example, inductive radio communication equipment can be used without permission only if its electric field strength is limited to  $15 \mu\text{V/m}$  or lower at a distance of  $\lambda/2\pi$  [6]. Permission is not required to use ISM equipment with RF output of  $50 \text{ W}$  or lower [7]. ISM equipment with RF output of higher than  $50 \text{ W}$  is subject to authorization. However, if RF output is  $500 \text{ W}$  or lower, for example, the field strength of leaked electromagnetic waves must be  $100 \mu\text{V/m}$  or lower at a distance of  $30 \text{ m}$  from the device [8].

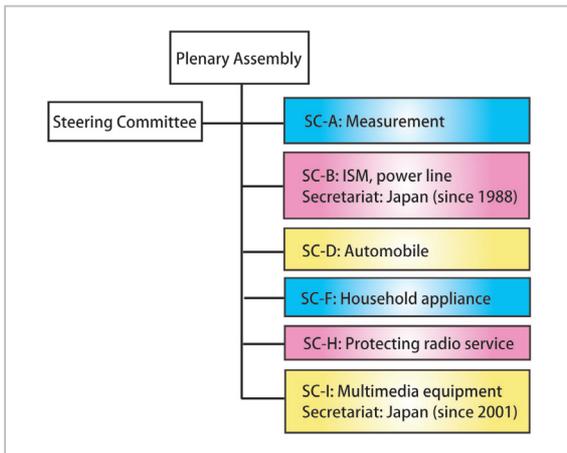
Since ISM equipment used for material processing and the like requires extremely high-power electromagnetic energy, the Law greatly eases permissible limits at specific frequency bands. Such a frequency band is generally referred to as an “ISM frequency band”. For example, in the case of a microwave oven that uses an ISM frequency band of  $2,450 \pm 50 \text{ MHz}$ , the permissible limit for in-band electromagnetic wave leakage is established at  $5 \text{ mW/cm}^2$  (with a field strength of  $138 \text{ V/m}$ ) [9] from the viewpoint of human body safety. In the HF band, the  $13 \text{ MHz}$  band is allocated to ISM equipment, and this band is widely used in dielectric heating equipment for drying lumber and thermo-compression bonding of plastics, among other applications. Since this

band can accommodate fairly high-level electromagnetic waves, a number of current communication systems also use this band, including RF-ID systems.

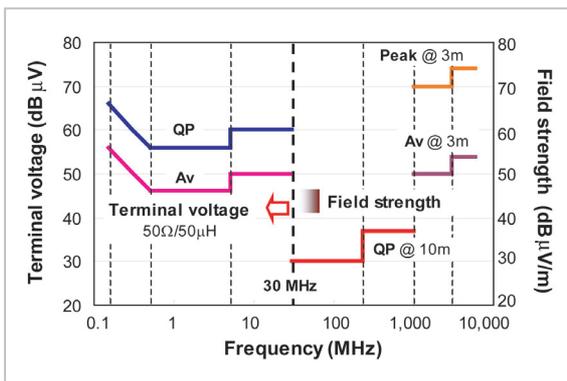
### 2.3 Electric/electronic devices

PCs and many other electric/electronic devices also emit unwanted radiation. The Radio Law stipulates that in the event of problems in radio services caused by unwanted radiation (i.e., disturbance) from a given device or equipment (other than radio or high frequency-based equipment), legal action is possible—for example, to halt the use of the device or equipment in question [10]. This reflects the importance of establishing measurement methods and permissible limits for unwanted radiation from various devices and equipment in protecting radio services and various electromagnetic environments.

At the global level, the International Special Committee on Radio Interference (CISPR) defines permissible limits for disturbance caused by high frequency-based equipment and electric/electronic devices. The domestic committee in charge in Japan is known as the CISPR Committee, under the auspices of the Telecommunications Council (established by the MIC). Figure 4 shows an organizational chart of the CISPR. The subcommittees (SCs) define permissible limits for equipment in given individual categories, with the aim of protecting broadcasting and radio communications. For example, the permissible limits shown in Figure 5 apply to IT devices with a frequency range of  $150 \text{ kHz}$  to  $6 \text{ GHz}$  [11]. At a frequency of  $30 \text{ MHz}$  or lower, leaked waves of longer wavelengths propagate along conductors such as power cables connected to the device. Therefore, the CISPR standards limit the disturbance current (or voltage) flowing through the connected conductors. At frequencies higher than  $30 \text{ MHz}$ , the wavelength of radiation from a device is close to the dimensions of the device itself, and direct radiation from the body becomes more noticeable. Therefore, in these cases the standards define permissible limits for field strength.



**Fig.4** International Special Committee on Radio Interference (IEC/CISPR)



**Fig.5** Permissible limits for disturbance caused by IT devices (CISPR 22-2003, Class B)

## 2.4 Comparison of permissible limits

The previous section described permissible limits for low-power radio services and for unwanted emissions by radio services, and permissible limits for disturbance generated by various types of equipment. However, these permissible limits cannot be simply compared with one another because measurement methods and conditions differ depending on the type of equipment. For example, ground-plane effects differ greatly depending on the frequency, height of the equipment, height of the measurement point relative to the ground, measurement distance, polarization, etc. In this section, I will compare various permissible limits by converting them into field-strength values measured at a distance of 10 m in free space (in which there are no ground effects).

The strength and radiated power of an electromagnetic wave generated from an infinitesimal element  $\Delta z$  of current  $I$  shown in Figure 6 are given for a distance of “ $r$ ” by the following equations, where  $\beta = 2\pi/\lambda$  :

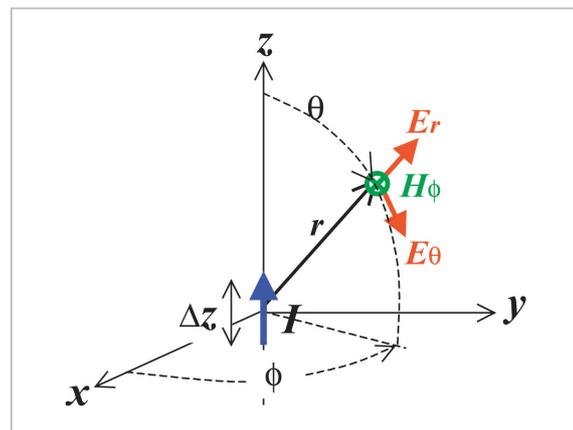
$$H = \frac{I \cdot \Delta z}{4\pi} j\beta \left(1 + \frac{1}{j\beta r}\right) \frac{e^{-j\beta r}}{r} \sin\theta \cdot \hat{\phi} \quad (1)$$

$$E = \frac{I \cdot \Delta z}{4\pi} j\omega\mu \left[1 + \frac{1}{j\beta r} + \frac{1}{(j\beta r)^2}\right] \frac{e^{-j\beta r}}{r} \sin\theta \cdot \hat{\theta} \quad (2)$$

$$+ \frac{I \cdot \Delta z}{2\pi} j\omega\mu \left[\frac{1}{j\beta r} + \frac{1}{(j\beta r)^2}\right] \frac{e^{-j\beta r}}{r} \cos\theta \cdot \hat{r}$$

$$P = 80\pi^2 \left(\frac{I \cdot \Delta z}{\lambda}\right)^2 \quad (3)$$

The above equations hold true if the size of the wave source  $\Delta z$  satisfies conditions “ $\Delta z \ll r$ ” and “ $\Delta z \ll \lambda$ ” and these equations are used to convert electric field strength values measured at a distance of 3 m into those measured at a distance of 10 m. A loop antenna is used to measure field strength at a frequency of 30 MHz or lower. In this frequency band, the magnetic field strength obtained by Equation (1) is used to determine the equivalent electric field strength (by multiplying the magnetic field strength by  $377 \Omega$ ). With respect to an electromagnetic field generated by current flowing through an infinite-length wired system, the equivalent electric field strength is determined using the following equation, which is obtained by Ampere’s law:



**Fig.6** Electromagnetic wave emitted from micro current element

$$E_{equi} = 120\pi \frac{I}{2\pi R} = 60 \frac{I}{R} \quad (4)$$

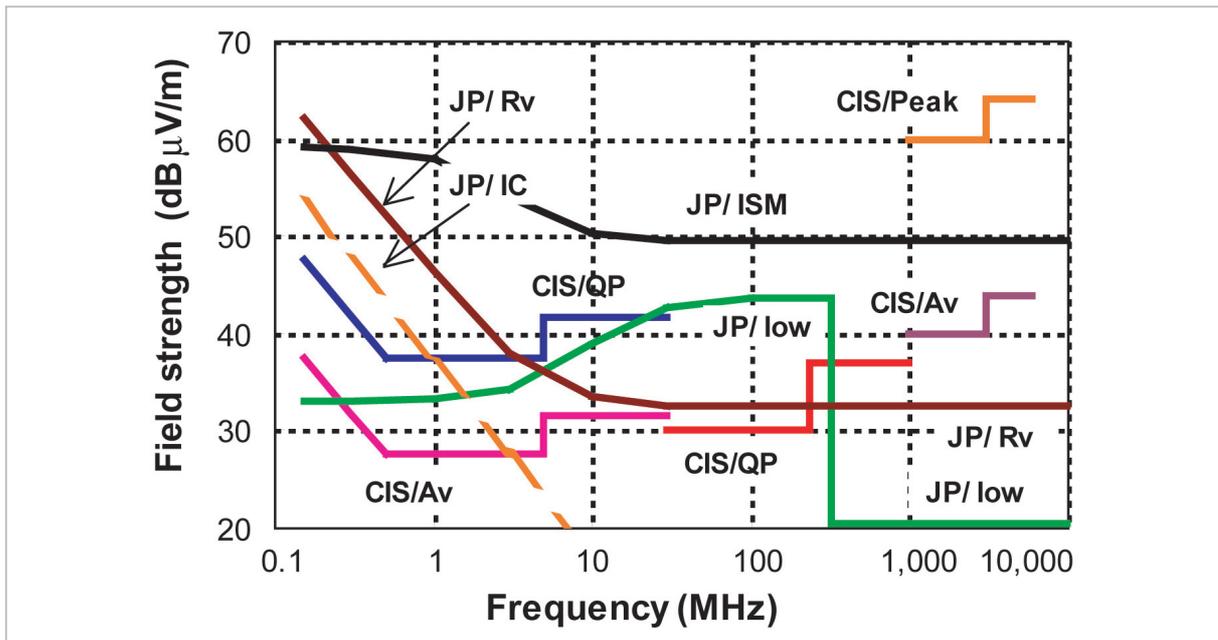
Figure 7 shows permissible limits for various types of devices and equipment converted into field strength values measured at a distance of 10 m. Specific conversion procedures are described below:

- (a) Low-power radio service (JP/low): Electric field strength values measured at a distance of 3 m are converted into those measured at a distance of 10 m, using Equation (1) when the frequency is 30 MHz or lower and Equation (2) when the frequency is higher than 30 MHz.
- (b) Incidental radiation from receiver (JP/Rv):  $I\Delta z$  is determined from Equation (3). This value is then substituted into Equation (1) or (2) to calculate the field strength measured at a distance of 10 m.
- (c) Inductive radio communication equipment (JP/IC): Equation (4) is used to determine current  $I$  corresponding to the permissible limit; the equivalent electric field strength is then calculated for a distance of 10 m.

(d) ISM equipment (JP/ISM): Electric field strength values measured at a distance of 30 m are converted into those measured at a distance of 10 m, using Equation (1) when the frequency is 30 MHz or lower and Equation (2) when the frequency is higher than 30 MHz.

- (e) Permissible limits set by CISPR (CIS/QP, Av, Peak): When the frequency is 30 MHz or lower, the permissible limit for terminal voltage is divided by  $50 \Omega/50 \mu\text{H}$  to determine the current value. This value is then substituted into Equation (4) to calculate the equivalent electric field strength at a distance of 10 m. At frequencies between 30 and 1,000 MHz it is not necessary to perform conversions, as permissible limits are defined at a distance of 10 m. When the frequencies are 1,000 MHz or higher, permissible limits at a distance of 3 m are converted into values at a distance of 10 m using Equation (2).

As shown in Fig. 7, permissible limits for unwanted radiation from various types of equipment with a frequency range of 3 MHz



**Fig. 7** Comparison of permissible limits for unwanted radiation from various types of devices and equipment

Converted to field strength values measured at a distance of 10 m. JP/low: low-power radio service in Japan. JP/Rv: incidental radiation from receiver. JP/IC: inductive radio communication equipment. JP/ISM: ISM equipment (50 to 500 W). CIS/QP: quasi-peak value set by CISPR 22. CIS/Av: average value set by CISPR 22. CIS/Peak: peak value set by CISPR 22.

to 3 GHz are 30 to 50 dB $\mu$ V/m. However, to achieve the common goal of protecting radio communication, it seems necessary to establish further consistency among these permissible limits. In particular, permissible limits for low-power radio services at 322 MHz or higher in Japan are extremely low; future revision is thus considered necessary.

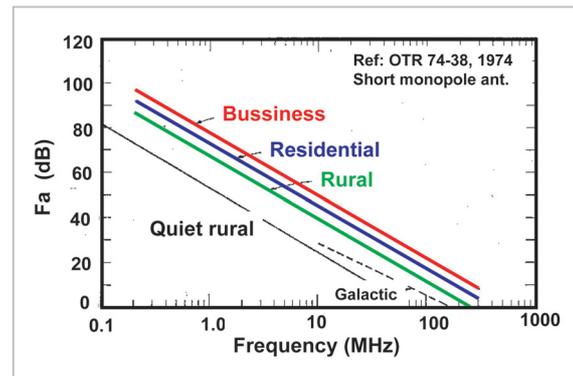
A Japanese government regulation stipulates the use of a measurement receiver with -6 dB bandwidth “B”, as shown in Fig. 2, when measuring electromagnetic waves emitted from a low-power radio service. These bandwidths are set in accordance with the CISPR standards[12]. However, in general the Japanese Radio Law does not include any provisions for specific bandwidths, nor does it address detection methods applied with the given measuring instruments. Therefore, different instruments may provide different measurement results, which is particularly inconvenient in radio administration. To address this problem, in principle CISPR instruments are now used to measure spurious emissions. In Fig. 7, permissible limits related to the Radio Law are converted based on the assumed use of CISPR instruments in measurement.

As described above, permissible limits at a frequency range of 3 MHz to 3 GHz are 30 to 50 dB $\mu$ V/m. If the field strength of electromagnetic waves emitted from a device is 40 dB $\mu$ V/m, this device emits unwanted radiation of approximately 33 nW per bandwidth B of the measuring instrument. The bandwidths of measuring instruments are 9 kHz at 3 MHz to 30 MHz, 120 kHz at 30 MHz to 1 GHz, and 1 MHz at 1 GHz to 3 GHz. If a device emits electromagnetic waves of 40 dB $\mu$ V/m (measured at a distance of 10 m) over the entire range of 3 MHz to 3 GHz, the total radiated power of unwanted emissions from this device will be approximately 0.4 mW. However, there is no possibility that unwanted emissions will occur over the entire frequency range, and the actual value will be on the order of microwatts ( $\mu$ W).

## 2.5 Ambient noise

The previous section described levels of unwanted radiation (radio noise) emitted from various types of radio equipment and electric/electronic devices. This section will briefly describe ambient noise levels, which correspond to the accumulation of such radiation.

Ambient noise includes natural noise caused by sferics and man-made noise. In the HF and UHF bands, man-made noise is more noticeable and occurs continuously. Figure 8 shows the statistical results of large-scale research on man-made noise environments conducted in the United States from 1966 to 1971. The researchers conducted measurement at 103 locations in different environments during the daytime. While moving in a monitoring vehicle or at fixed measurement points, they received eight to ten frequencies within a range of 250 kHz to 250 MHz at the same time, and measured radio noise[13]. In the figure, “ $F_a$ ” refers to a noise figure defined by the following equation:



**Fig.8** Frequency characteristics of ambient man-made noise (ITU-R P.372-8)

$$F_a \equiv P_{av} / (kTB) \quad (5)$$

When a monopole antenna is used in measurement, the amount of received power will be reduced by half relative to a dipole antenna. Therefore, received power is expressed by the following equation:

$$P_{av} = \frac{E^2}{120\pi} \frac{\lambda^2}{4\pi} G = \frac{E^2}{120\pi} \frac{\lambda^2}{4\pi} \frac{1.5}{2} \quad (6)$$

By substituting “ $T = 290 \text{ K}$ ” and the Boltzmann constant “ $k$ ” into Equation (5), we obtain an equation for field strength (median value) and a noise figure from Equation (6). In this equation, “ $B$ ” refers to the equivalent noise bandwidth (Hz) and “ $F_a$ ” refers to the reading (dB).

$$E_n = F_a + 20 \log f_{\text{MHz}} + 10 \log B - 95.5 \quad (\text{dB}\mu\text{V/m}) \quad (7)$$

Equation (5) is based on the assumption that ambient noise occurs over a wide frequency band and that the measured field strength is proportional to the square root of the instrument’s bandwidth. It is likely that this assumption was derived from the fact that the instrument used in the measurement shown in Fig. 8 featured a limited equivalent noise bandwidth of 4 kHz and the noise sources were at some distance from the measurement points (and thus the central limit theorem held true). We also should consider the following when reading Fig. 8: since a man-made noise source often generates periodic noise, it may have many spikes in the spectrum measured near the source; the results of the measurement conducted on the street might have been influenced by passing automobiles; it is highly doubtful whether the measurement results obtained more than 30 years ago are valid today; there have been subsequent increases in power consumption and the significant progress in electric/electronic equipment. Given the above facts, it would seem necessary to conduct new research on ambient noise in Japan.

In the Study Group on High-Speed Power Line Communication of MIC, we discussed the issue of ambient noise in the HF band. We made an estimation of the field strength of ambient noise based on the data shown in Fig. 8. Table 1 shows the results of this estimation. We found that ambient noise may exceed the sensitivity of various radio services that use this frequency band[1]. Note that the estimation results in Table 1 are based on research conducted in the United States more than 30 years ago; it is safe to assume that current

**Table 1** Field strength of ambient noise  $E_n$  (dB $\mu$ V/m):  $B = 10 \text{ kHz}$

	2 MHz	3 MHz	10 MHz	30 MHz
Business area	19.0	17.6	13.6	9.9
Residential area	14.7	13.3	9.3	5.6
Rural area	9.4	8.0	4.0	-0.3
Area with very little noise	-4.5	-6.0	-10.5	-14.6

noise levels are higher than these values.

### 3 Propagation of electromagnetic waves

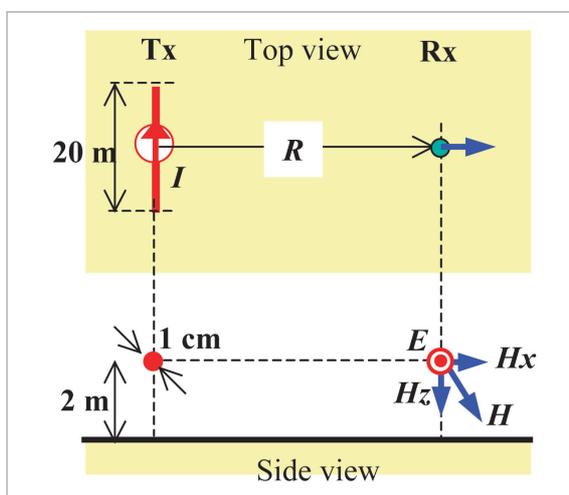
In Section 2.4, I described calculations of the distance characteristics of electromagnetic field strength in free space (in which there are no ground effects) using an infinitesimal current element and current flowing through an infinite-length wired system. However, these theoretical assumptions do not hold true in the case of an ordinary source of unwanted radiation. In the sections below, we will discuss propagation of electromagnetic waves emitted from a power line and shielding effects of buildings to analyze possible effects of HF-band PLC.

#### 3.1 Wave propagation over a short distance

It is possible to estimate easily and accurately the level of electromagnetic waves generated from a finite-length wired system by the moment method (MoM) calculations, provided that the ground surface is flat and the measurement point is located within a line-of-sight distance (within a few kilometers when the height of the transmitter is 2 m). This section will describe the calculation results for emissions from a power line of HF-band PLC using NEC-2, a widely used moment method program.

For the sake of simplicity, we picked up only one type of indoor wiring and assumed that a linear antenna measuring 20 m in length ( $L = 20 \text{ m}$ ) is placed horizontally at a height of 2 m ( $H_t = 2 \text{ m}$ ) from the ground, as shown in

Figure 9. At a height of 2 m ( $H_r = 2$  m), we calculated electromagnetic fields while varying the distance “R”. Although this antenna is extremely long, it can be considered as a point source when seen from a distance of 50 m or more in this frequency band. RF power is fed from the middle section of the antenna. However, since this is a fixed-length wired system, standing wave current is generated along the antenna. For this reason, we fixed the maximum value of the standing wave current “ $I_{max}$ ” at 1 mA to determine the distance characteristics of the electromagnetic fields. We assumed that the ground is “wet” or “medium dry”, which generally reflects the soil conditions in Japan.



**Fig.9** Magnetic field generated by current through a horizontally placed wired

(a) Electromagnetic field generated by current through horizontally placed wired system

Figure 10 shows the attenuation characteristics for magnetic field strength in the horizontal direction when electromagnetic waves are emitted from a linear antenna (20 m long) placed horizontally at a height of 2 m from wet ground. We calculated the field strength for maximum current on a single line of 1 mA.

When the ground is medium dry, the magnetic field strength becomes less dependent on the frequency due to reduced effects of ground reflection. There was little difference in the calculation results between the cases of wet

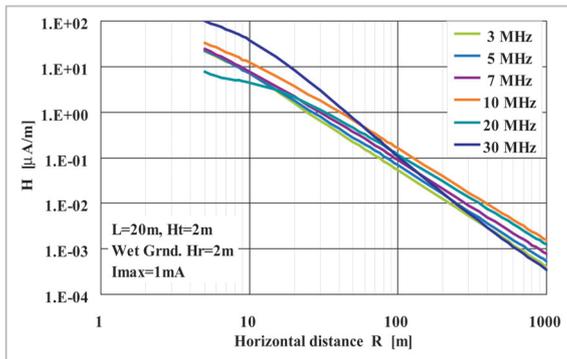
and medium dry ground. We also calculated the electric field strength, and the ratio between the magnetic and electric field strengths was close to a characteristic impedance of  $377 \Omega$ . As shown in Fig. 9, the wired system is placed horizontally, and horizontally polarized waves reflected by the ground are out of phase with the direct wave. Therefore, at a distance of 10 m or farther from the system, electromagnetic field strength is attenuated inversely to the square of the distance.

In the direction of height, an electromagnetic field (generated by a horizontally placed wired system) is attenuated inversely to the first power of  $H_r$  (height of the receiving point) if the height of the receiving point is greater than a distance of  $\lambda/2\pi$  ( $H_r \gg \lambda/2\pi$ ) and is sufficiently greater than the length of the antenna ( $H_r \gg L$ ). At a closer location, the electromagnetic field is attenuated inversely to the square of the distance. In the vicinity of a frequency  $f_{MHz} = 75/H_t$  [MHz], the strength of emitted waves may increase nearly twofold due to ground reflection. As shown in Fig. 11, the level of the electromagnetic field varies greatly depending on the frequency. When viewing Fig.10 for comparison, we can see that the amount of attenuation is smaller in the vertical direction than in the horizontal direction.

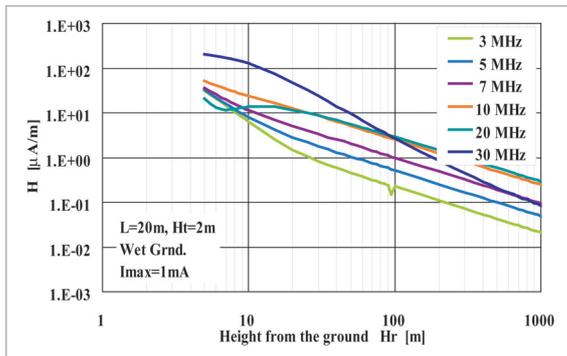
(b) Electromagnetic field generated by current through vertically placed wired system

We also performed calculations of electromagnetic fields when high-frequency current is passed through a vertically placed wired system, as shown in Fig.12. In this case, the wired system was a single conductor measuring 5.6 m in length ( $L = 5.6$  m) and the middle section of this conductor was located at a height of 3.2 m. Power was fed from the middle section and the maximum current on the system “ $I_{max}$ ” was 1 mA. We selected an antenna length of 5.6 m assuming installation of a PLC system in a two-story house. We performed moment method calculations for the cases of wet and medium dry ground.

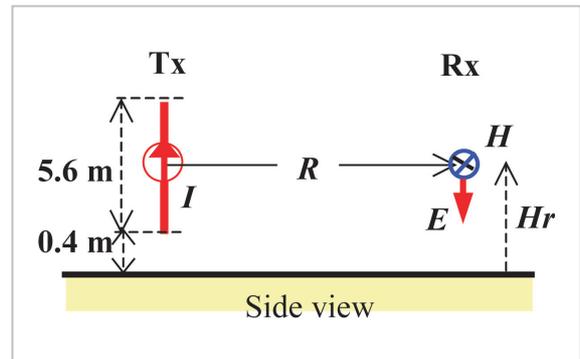
Figure 13 shows the calculation results. Compared with the values for Fig. 10, the



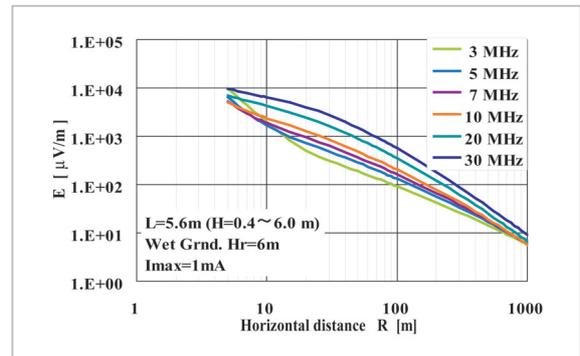
**Fig. 10** Distance dependence of magnetic field generated by current through horizontally placed wired system (Wet ground,  $H_t = 2$  m)



**Fig. 11** Height dependence of magnetic field generated by current through horizontally placed wired system (Wet ground,  $H_t = 2$  m)



**Fig. 12** Electromagnetic field generated by current through vertically placed wired system



**Fig. 13** Distance dependence of electric field generated by current through vertically placed wired system (Wet ground,  $H_r = 6$  m)

field generated by the vertically placed wire become relatively noticeable because its attenuation is less than that of the horizontal wire field. At a greater distance, however, the ground reflection coefficient of vertically polarized waves approaches  $-1$ . Therefore, the electromagnetic field strength is attenuated inversely to the square of the distance, as in the case of horizontally polarized waves.

### 3.2 Wave propagation over a medium to long distance

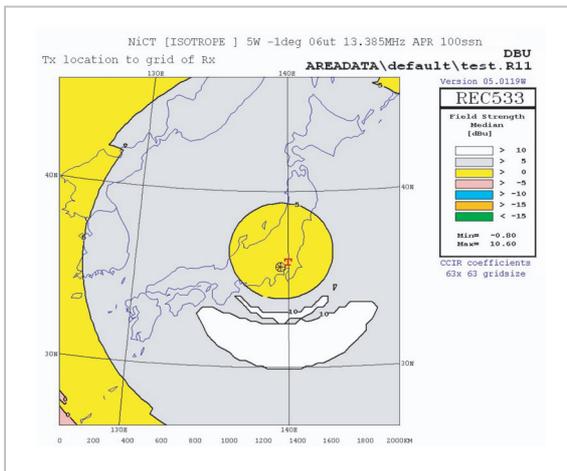
When studying propagation in the HF band over a medium to long distance, we must consider not only ground waves but also electromagnetic propagation by sky-wave (i.e., those reflected by the ionosphere). Therefore, field strength is expressed as a function of ionospheric characteristics, which change in a complicated manner. For example, if electric power  $P_t$  is input to a transmitting antenna

with a gain of  $G_t$  in free space, the field strength of electromagnetic waves at a distance “ $r$ ” is given by the following equation:

$$E = \frac{\sqrt{30G_t P_t}}{r} \quad (8)$$

In the case of ionospheric propagation, however, “ $r$ ” is the distance of apparent oblique propagation. Many other factors must also be taken into consideration, including reflection, absorption, and scattering of waves by the ionosphere and ground reflection loss. The calculation procedure soon becomes extremely complicated. We used a commonly accepted software program for a propagation model based on ITU-R Recommendation P.533, “HF propagation prediction method”. Figure 14 shows the calculation results for the distribution of field strength in and around Japan, when a 5-W source located at NICT emitted electromagnetic waves at a frequency

of 13.39 MHz. As shown in the figure, the field strength of sky-waves peaks at a distance from the emission point and this peak location varies depending on the frequency, incident angle, and ionospheric conditions. A “hot spot” is sometimes generated at this peak location, but here electromagnetic field strength is not high because the waves are attenuated due to the oblique propagation distance described in Equation (8). Naturally, the electromagnetic field strength becomes highest in the vicinity of the transmission source, within the range of the ground waves.



**Fig. 14** Distribution of field strength in the case of ionospheric propagation (Using 5-W, 13.39-MHz transmission source located at NICT)

### 3.3 Electromagnetic shielding effects by buildings

If a PLC transmitting or receiving point is surrounded by a building or other structure, electromagnetic waves are shielded. In this section, I will briefly describe the results of computer simulation of such electromagnetic shielding effects, citing a report from the Study Group on High-Speed Power Line Communication[1][14].

We performed simulations of three rectangular box-shaped structures made of a steel frame, wood, and reinforced concrete, respectively. These structures were all of the same size: 3.0 m (W) × 3.9 m (D) × 3.2 m (H), and each featured a door and window at the front

and back. To measure PLC wave leakage, we used a wave source consisting of a 6-m power line routed in an angulated U-shape. We performed numerical analysis using commercially available finite integration software.

Since the distribution and level of electromagnetic fields differ markedly depending on the presence of a building, we expressed the shielding effect as a ratio between field strength values calculated in the presence of a building and in the absence of such a structure. We obtained average values for locations 10 m and 150 m away from the source. Table 2 shows the calculated results. As you can see, reinforced concrete structures are expected to provide shielding effects of 20 dB or higher in the HF band while wooden structures provide shielding effects of only about 10 dB.

**Table 2** Electromagnetic shielding effects of buildings

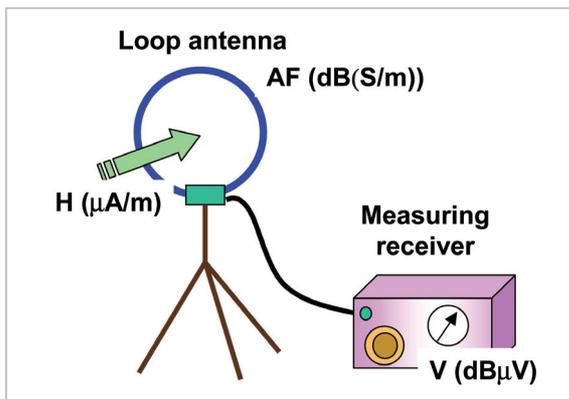
	Reinforced concrete				
Frequency	2MHz	5MHz	10MHz	20MHz	30MHz
Attenuation (10 m away)	29dB	28dB	23dB	27dB	31dB
Attenuation (150m away)	28dB	26dB	22dB	27dB	29dB
	Wooden				
Frequency	2MHz	5MHz	10MHz	20MHz	30MHz
Attenuation (10 m away)	22dB	16dB	12dB	10dB	6.8dB
Attenuation (150m away)	15dB	16dB	13dB	7.6dB	5.0dB

## 4 Measurement of HF-band electromagnetic environment

To perform measurement of an HF-band electromagnetic environment, the strength of the electromagnetic field is determined using a loop antenna connected to a measuring receiver such as a spectrum analyzer, as shown in Fig. 15. In this case, strength is calculated based on the loop antenna’s magnetic field antenna factor “ $AF_H(\text{dB}(\text{S}/\text{m}))$ ” and the receiver’s reading “ $V(\text{dB}\mu\text{V})$ ”, using the following equation:

$$H [\text{dB}(\mu\text{A}/\text{m})] = V [\text{dB}(\mu\text{V})] + AF_H [\text{dB}(\text{S}/\text{m})] \quad (9)$$

To measure a low-level electromagnetic



**Fig. 15** Measurement of HF-band electromagnetic field (using a loop antenna)

field, an antenna with a small “antenna factor” is employed. Such an antenna needs to feature a large loop with a number of turns. However, when the loop becomes larger, the antenna’s positional resolution will decrease, and when the number of turns increases, resonance will occur at a low frequency range, which should be avoided. Therefore, we normally use a single-turn loop antenna 60 cm in diameter[12]. In a high-frequency magnetic field, the electromotive force of a loop antenna changes in proportion to the frequency and loop area. The magnetic field antenna factor  $AF_H$  decreases in proportion to the frequency, but the antenna will usually present more complicated characteristics because the inductance of the loop increases in proportion to frequency. Certain commercially available loop antennas have a resonant circuit to eliminate this inductance.

Monopole antennas are also available for use in measurement in the HF band. However, this type of antenna is susceptible to the effects of surrounding objects, including the individuals performing the measurement. Therefore, loop antennas are generally used to measure electromagnetic fields in the HF band. These antennas provide measurement values of magnetic field strength [dB (A/m)], but it is still more common in Japan to use equivalent electric field strength [dB (V/m)], which is calculated by multiplying a measurement value by a characteristic impedance of  $377 \Omega$  (The CISPR began to use magnetic

field strength about ten years ago.).

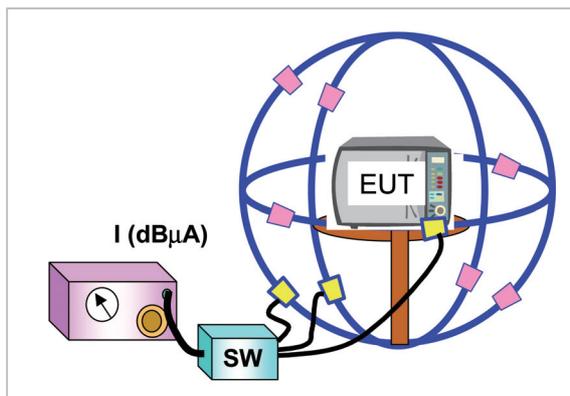
A commercially available spectrum analyzer has an equivalent input noise level of approximately  $-140 \text{ dB (mW/Hz)}$  in the HF band. With this level of noise, a quasi-peak value is calculated without input ( $B = 9 \text{ kHz}$ ). CW input is then calculated when the analyzer’s indication increases by  $6 \text{ dB}$ —to arrive at approximately  $10 \text{ dB}\mu\text{V}$ . In the case of a commercially available EMI measuring receiver, the value of a CW input corresponding to that of the above analyzer is approximately  $-5 \text{ dB}\mu\text{V}$ . As you can see, the EMI measuring receiver described here enables us to extend the range of measurable strength of electromagnetic fields downward by  $15 \text{ dB}$ .

The magnetic field antenna factor  $AF_H$  of a loop antenna is between  $-10$  and  $-20 \text{ [dB(S/m)]}$  in the HF band. Given the sensitivity of the measurement system mentioned above, it becomes possible to measure a magnetic field ( $B = 9 \text{ kHz}$ ) featuring strength of approximately  $-10 \text{ dB (}\mu\text{A/m)}$ . This value corresponds to an equivalent electric field strength of approximately  $40 \text{ dB (}\mu\text{V/m)}$ . Using average detection, it is possible to extend the measurable strength level further, by approximately  $10 \text{ dB}$  downward.

However, to measure the strength of ambient noise at the levels shown in Table 1, it is necessary to improve sensitivity even further—by  $20 \text{ dB}$  or more. To achieve this, we must use a variety of techniques, such as measurement of amplitude probability distribution (APD). Some commercially available loop antennas or measuring receivers feature a low-noise preamplifier to improve sensitivity. When using such an instrument, it is important to note that a measurement value may be erroneous due to the preamplifier’s nonlinear response when a strong broadcasting/communication wave exists.

Under an ordinary method for measuring disturbance, a loop antenna is placed  $10 \text{ m}$  from a device under measurement. Therefore, the field incident on the antenna is low and preventing the effects of extraneous wave incidence is difficult. To address this problem, a

“large loop antenna system” is used to measure the magnetic fields of electronic devices at frequencies below those of the HF band. This antenna consists of three orthogonal loops, as shown in Fig. 16.



**Fig. 16** Large loop antenna system

## 5 Conclusions and acknowledgements

In recent years, new HF-band communication systems have appeared, from RF-ID tags to power-line communication (PLC) systems, all of which are expected to undergo explosive

growth in use. It is thus essential that we establish electromagnetic compatibility among various types of communication equipment (including radio equipment) and electric/electronic devices.

This paper described a comparison of various noise sources that create electromagnetic environments and their permissible limits at a frequency range of 150 kHz to 10 GHz. As a result of these comparisons, we demonstrated the necessity of ensuring consistency among permissible limits for various types of equipment and devices, and of conducting comprehensive studies on today’s noise environment. This paper also described methods for measuring HF-band electromagnetic fields and mentioned a number of issues concerning the measurement of ambient noise.

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***SUGIURA Akira, Dr. Eng.***

*Professor, Research Institute of Electrical  
Communication, Tohoku University*

*Communication Environmental Engi-  
neering*